DISCUSSION BEFORE THE WIRELESS SECTION, 13TH MAY, 1935

Mr. P. W. Willans: The author's specification for a high-fidelity radio-gramophone is of very great interest, but, from the practical demonstration he has given us, particularly from the record of organ music which was played on his instrument, I gained the impression that there was non-linear distortion of rather a serious kind. I should be glad to know whether the question of linear response in respect of every part of the apparatus has been investigated as thoroughly as for the pick-ups which he uses.

With regard to the curves given in the paper on this last-named matter, I welcome the study of linearity, which the author has made almost more, as a matter of detail, than any other feature of the paper. I think that we have suffered for far too long in the industry from pick-ups giving non-linear distortion, and, now that it has been proved commercially practicable to design a pick-up the function of which is simply to translate mechanical into strictly proportionate electrical vibrations, any desired frequency correction being applied in the electrical system, I hope that this practice will become standard. We have had too much experience in the past of pick-ups which depend on the non-linear qualities of the magnetic circuit and the mechanical

resonance of the tone-arm to give bass boost; this leads to non-linear distortion and bad tracking and is absolutely indefensible.

There is one matter of detail which I should like to mention, concerning the design of amplifiers having flat band-pass characteristics, and it is possibly opportune to refer to it here since, during my service with the author's company, I communicated certain calculations on this subject to Mr. W. H. Connell who, I believe, made practical use of them in designing amplifiers for radio purposes.

It has been known, in a general way, that it is advantageous, in designing a multi-stage band-pass amplifier, to make some of the stages with circuits of low damping and tight coupling and others with circuits having high damping and loose coupling. To put the design on a quantitative basis we may modify a method first published by Butterworth* and applied to the design of filter amplifiers in general. His method consisted in designing a whole amplifier to give a cut-off characteristic the response ratio of which takes the form $1/\sqrt{(1 + Kf^n)}$ (f being the frequency and K a constant) by splitting the expression under the radical sign into a number of factors and designing one stage of amplification to correspond to each factor.

For the purpose of illustration we may take a 3-stage tuned-transformer-coupled amplifier in which each inter-stage coupling consists of a pair of identical coupled circuits. The response ratio of one such stage may be generally represented by the expression:—

$$\frac{\text{Constant}}{\sqrt{\left[1 + 2y\frac{\beta^2 - k^2}{\beta^2 + k^2} + y^2\right]}} \quad . \quad . \quad . \quad (1)$$

where $y = \dfrac{4f_a^2}{f_r^2(\beta^2 + k^2)}$

f_a, f_r = audio and radio frequencies respectively;

$\beta = R/(\omega L)$ for each circuit;

k = coefficient of coupling.

The desired response of the whole amplifier will follow the formula:—

$$\frac{\text{Constant}}{\sqrt{[1 + y^6]}}$$

and since the denominator may be split into factors according to the identity

$$1 + y^6 \equiv (1 + y^2)(1 + \sqrt{3}y + y^2)(1 - \sqrt{3}y + y^2) \quad (2)$$

we arrive at the correct design by making the formula (1) correspond to each of the factors of (2) in succession.

By simple algebra we find that $\beta^2 + k^2$ must be the same for all stages and the ratio β^2/k^2 must have the values $(2 + \sqrt{3})/(2 - \sqrt{3})$, 1, and $(2 - \sqrt{3})/(2 + \sqrt{3})$ for the three stages respectively. The value of $\beta^2 + k^2$ determines the cut-off frequency attained.

It will be evident, on reference to Butterworth's article, that this method can be applied to amplifiers of this type having any number of stages, and also to mixed audio- and radio-frequency amplifiers.

* *Experimental Wireless*, 1930, vol. 7, p. 536.

This *modus operandi* is useful in practice because it is quite readily possible to set up a tuned transformer to a given coefficient of coupling by measuring the high-frequency resistance thrown by one circuit into the other. If this is equal to the resistance of the latter circuit by itself (I am now assuming that they are identical circuits) we get the critical case of a tuned transformer giving a square-topped characteristic. If we make the coupling stronger we get the so-called " band-pass " adjustment with two humps, and if we make it weaker we obtain a single peak. The quantitative relations follow from quite simple reasoning which need not be given here.

I should be interested to know whether practical use has been made of these formulæ in the design of the present high-fidelity radio-gramophone.

Mr. P. K. Turner: I propose to confine my remarks to one particular point, which I am sorry to say is a criticism on a matter of principle.

Some years ago, the Bell Telephone Laboratory produced an equipment which had a substantially flat characteristic from 20 or 30 to 14 000 cycles per sec., and with that they did some classic work. Among other things, they conducted a series of tests (which I think everybody accepts) which proved that for ordinary music a defect was noticed by a good audience directly the transmitted band fell inside the limits of 40 to 10 000 cycles per sec., and that for " effects " and sundry noises that band had to be extended up to the full 14 000 cycles. They referred to this equipment as a " high fidelity " equipment, and we have thus fallen into the habit of referring to apparatus as " high fidelity " when—if not perfect—it is at any rate so good that no ordinary ear could appreciate any difference when it is improved or made perfect. Now, unfortunately, we have no word left to convey that idea; for in this paper we have not only " high fidelity " but " extra high fidelity," which, however good it may be as a commercial proposition, falls far below the standard I have mentioned. Our standard has been taken away from us, and I shall be glad if anyone can suggest a new word which we *can* apply only to an equipment which is really faithful.

Mr. C. E. G. Bailey: In the radio-frequency portion of the author's instrument the point of design which I most query is the provision of very little preselection for short-wave stations. Short-wave stations are springing up fairly rapidly, and there is already some congestion in the neighbourhood of 6 and 15 megacycles per sec. With all superheterodyne receivers having little or no preselection a certain amount of programme interference is definitely noticeable, and it might be worth while in this equipment to employ a higher intermediate frequency or the existing intermediate frequency with an additional oscillator stage, giving a double superheterodyne effect.

With regard to the medium and long wave-bands, it is very interesting to notice that the image ratio has been reduced to 50 000 : 1, i.e. to a value which is negligible for all practical purposes; but there is another effect which one usually finds is more troublesome than the image effect when the latter has been reduced to, say, 10 000 : 1, and that is the effect of the intermediate-frequency harmonic feed-back. When a signal arrives

and is transformed into intermediate frequency, on arriving at the second detector it produces harmonics. These harmonics are by no means negligible, because with linear detection they only decrease in intensity in accordance with their harmonic number. If the 2nd harmonic is of strength $\frac{1}{2}$ with reference to some arbitrary level, the 12th will only be of strength $\frac{1}{12}$, and so on; and therefore a suitable attenuation of these harmonics, to prevent them arriving at the aerial or radio-frequency stage and there mixing with the incoming signal, is a very difficult problem. The suppression of the 2nd harmonic is difficult, and trouble has been caused even with harmonics as high as the 12th. I should therefore like to know whether any figures are available for the reduction which has been achieved.

With regard to the intermediate frequency, I have noticed the following anomalous effect when a band-pass circuit follows the frequency-changer. When the selectivity curve is plotted by varying intermediate-frequency input, the intermediate amplifier may be set up so that it gives a thoroughly symmetrical curve, but when this intermediate frequency is replaced by a signal frequency the previously balanced curve is replaced by one which is slightly out of balance. It would be interesting to know whether in the author's receiver the overall selectivity curve is symmetrical.

Passing on to the " Q " circuit for the suppression of all but wanted signals, I should like to query the stability of this circuit in practice, and to ask whether due provision has been made for the fact that circuit constants may drift with time. This circuit is of importance, because if its frequency varies slightly in the course of some months of use the user will be compelled to tune to a frequency slightly differing from the centre of the intermediate-frequency characteristic, with consequent poor reproduction.

I notice that the A.V.C. (automatic volume control) has been increased on short waves, but I question the usefulness of the practice of putting A.V.C. with high delay level on short waves. Since short-wave signals spend so much of their time between inaudibility and faint audibility, I consider that A.V.C. is more effective if operating with zero delay and exercising some control over the faint portions of the signal. Sensitivity is lost by this means, but, with a receiver of the sensitivity claimed, this loss should not be too severe.

Passing to the audio-frequency section of the equipment, when the volume control is turned down a certain amount of low-frequency enhancement is brought in to correspond to the different characteristics of the ear at different levels. It is surely desirable to bring in high-frequency enhancement at the same time, because it is well known that the ear increases its sensitivity in the middle regions and loses it simultaneously at the low and high frequencies. I should like to ask whether the possibility was envisaged of including, instead of a parallel-resonant circuit at low frequencies, a series-resonance circuit of a mean frequency.

The harmonic percentage analysis was taken, presumably, from the detector input level onwards, and therefore the figures obtained are all for the harmonics, including their enhancement by the acoustic circuit; but if taken at slightly higher frequency these harmonics would be fairly considerably increased, and in particular in the full bass-cut position the 2nd harmonic would be increased by about 2·2 and the 3rd by about 3·5 times. It would be interesting to know whether the high-note boost or any other portions of the circuit which might have a similar effect were in position at the time the measurements were taken, because, in common with Mr. Willans, I suspect a certain amount of non-linearity in the overall curves, after listening to some of the records. I thought this effect was more evident in the case of the violin than in that of the organ. I should like to have the author's comments on the effect of tuned high-note boost on transients. Is the high-note boost critically damped? I think that in the radio demonstration the very slight static clicks that came through rang for a little fraction of a second, giving an effect of hiss which was rather out of proportion to their volume; and this, of course, would be accounted for if the high-note circuits were not critically damped.

I should like to express my appreciation of the usefulness of the empirical tests of the complete receiver in a typical room, and of the general usefulness of the experimental work carried out throughout, enabling the faults to be checked before they had time to go too far. Too little work has been done on the problems of receivers under actual working conditions, and very much reliance is placed on the behaviour of the components in positions where they will never have to function in practice. An example of the use of this experimental work is the discovery that the radio and amplifier chassis and the record-playing mechanism were as effective for damping purposes as cotton wool.

Mr. A. H. Cooper: Towards the end of his remarks Mr. Bailey said something which I feel ought to be considered in conjunction with the earlier remarks of Mr. Willans, to the effect that a great deal had been done on the behaviour of components in positions in which they would never have to function in practice. I think that is a fairly good description of the mathematics which we have had from Mr. Willans. That mathematical reasoning is an excellent thing to be taken in a small dose at the beginning of the design of a cascaded intermediate-frequency amplifier, and also for purposes of comparison at the end of the design period; but in the middle of the design period, when, I am sorry to say, all the work is done, it is a dangerous thing to look at; it is so profoundly altered by the reaction round the stages. That reaction can, I know, be expressed as a part of the radio-frequency resistance, and that is why I say that at the end of the design period it is a good thing to look at this to see whether under actual operating conditions the coils have the performance that is called for. It is dangerous, however, in the beginning to sit down and work out the resistance we require, and say: " I will wind a certain amount of wire and measure its resistance, and go on doing this until I have the right sort of resistance, and then I will put that into the amplifier and the amplifier will be perfect." It will not. It is because of that sort of thing that Connell and Huxter spent a year on experiments. In the end I believe their results are rather like the values given by Mr. Willans, if we make due allowance for the reactions and if we measure them under the conditions in which they are

working at one particular level of input on the receiver. It is quite possible that the particular formula given by Mr. Willans truly describes the receiver at one particular level and when the receiver is tuned to one particular station.

None of the previous speakers has referred to the subject of contrast amplification. I have heard it said several times that contrast amplification is all wrong, and that what is wanted in a receiver is just the converse of the controller who is sitting down and turning knobs when the input to the microphone is changed. We have not achieved that, and therefore we have not achieved what we ought to have set out to achieve. I am afraid that we never shall achieve it unless we have some system based on a telepathy channel between the studio and the receiver, or some sort of pilot channel. There is another way of looking at the matter. We are not trying solely to replace the contrast which is lost; we are trying to enhance the contrast. We have seen all sorts of exaggerations in radio—exaggeration of the low notes, exaggeration of the high notes, and indeed every sort of exaggeration that was possible. Now we are offering another exaggeration, exaggeration of contrast. This type of exaggeration is an artifice which is permitted in many of the arts—literature, music, and photography. It is a form of retouching. Retouching is something to which we as scientists may object; it is a thing not to be allowed in any scientific photograph, but only for portrait work.

Dr. A. Gordon-Finlay: I should like to touch on an aspect of the subject of high-fidelity reproduction that has not been dealt with this evening and on which, as far as I know, comparatively little has been published. It is, nevertheless, pertinent to the subject of the present paper. I think it must be evident that, to whatever extent we may improve our technique along the present lines—and the author has given a good idea of the work that is being done in this direction—the final result must nevertheless achieve something short of a perfectly reasonable ideal, something less than realism, because it differs fundamentally and absolutely from reality in being drawn in a single dimension. I have recently been a good deal interested in the question of binaural reproduction as applied both to broadcasting and, in particular, to the gramophone, and have come to the conclusion that the results obtainable warrant serious attention in the near future.

I think we will be ready to agree that the voice of a singer or the music of an orchestra heard in the three-dimensional reality of the concert hall is a different thing from the same voice or the same music heard in the loud-speaker. I think it will be agreed, too, that the reasons for this involve more than the mere question of linear response over the audible spectrum. If we were able to reproduce exactly at the loud-speaker the sounds impinging on the microphone, so that oscillographic records of the two were identical over the musical range, we would still have the difference that exists between the flat picture on the wall and the living reality with substance and location in space and time, and this, at the present state of the art, is coming within measurable distance of being the whole difference. It is at all events the difference between "qualified fidelity," which may mean anything, and fidelity, which means only one thing, and it is in fidelity that the ultimate future of broadcasting, of television, of the film, and of the gramophone, alike lies.

It is rather a big subject, and there is no time to deal with it adequately, but I should like to offer a few notes on it that may have some interest, and to ask one or two questions arising from the paper.

Firstly, where we have echo we have in effect a second dimension in sound reproduction that is the equivalent of perspective in the flat picture. We know the difference that this involves, and deliberately use it both in broadcast and in gramophone technique. By doing so, we get depth in our acoustic picture, and take a step nearer to realism that everyone can appreciate. The dimension we still lack is breadth. To obtain that dimension, binaural audition is required, and this has the same importance and the same effect as binoptical vision in its field. The extent of that importance need not be stressed. There is nothing new about it, and work has been done on it in this country, in Germany, and in America. The question is rather how it can be realized as a practical proposition, and it is in that direction that my own experiments have lain.

The method used to obtain the binaural effect has been the usual one of installing two microphones in different spatial relation to the sound source, separate gain amplifiers associated with them, and separate output equipment feeding either into telephone receivers independently poled or into loud-speakers separately fed and disposed. The two amplifiers are combined in one box, and consist of straightforward resistance-coupled triode-pentode combinations, coupled in paraphase and providing an output up to 11·5 watts linear within rather better than the usual definition. The microphones are high-class moving-coil instruments, and the loud-speakers two pairs of moving-coil/piezo-electric balanced combinations on 48-in. damped baffles, disposed in adjustable relation to one another. Piezo-electric movements are also used in the pick-up heads, and tone-correction is applied in circuits intermediate between microphone and amplifier and pick-up and amplifier, respectively. There is little to say about this part of the equipment except that particular care has been taken in the design to ensure a high order of initial fidelity, the overall response being linear within 5 decibels over the band 28 to 10 300 cycles. It is therefore better than the records, and is capable of reproducing satisfactorily whatever can be got on the records.

Starting on this premise, the chief interest centred on the actual recording and means of combining the two outputs in appropriate acoustic relationship. The first and simplest plan was to take two simultaneous records from the two microphone lines by means of two stroboscopically synchronized recording tables, and to reproduce them in a similar way on two synchronized turntables feeding the respective outputs. The results were startling, but not altogether satisfactory owing to the (not unexpected) difficulty of maintaining synchronism throughout the run of the records. An interesting effect that arose was an artificial echo due to small variations in synchronism, which caused the character of the reproduction to vary at intervals

between that in a small space and that in an immensely large one, producing a very weird effect not, however, without potential applications. On the whole, the advantage of binaural reproduction emerged very clearly, and was regarded as justifying the trouble of improving the technique.

The next step, therefore, was to link the turntable pairs in permanent mechanical relationship, and this was done by mounting them on one baseboard and connecting them together with a non-elastic driving band, which was simpler and cheaper for the experiments than arranging a common drive. This enabled synchronism to be more nearly maintained and gave much improved results, but trouble was still experienced owing to slight record slip on the turntables under the drag of the heaviest passages, and to difficulty in starting the records synchronously in the first instance. These difficulties were overcome by articulating the centre spindles so as to obtain a positive drive and enable the records to be inserted only in a definite relationship, the pick-up heads also being linked, and there was now nothing to prevent the assembly from being mounted in a fair-sized cabinet and operated almost as easily as a normal gramophone instrument.

It still involved the use of two turntables and two sets of records, however, and normal self-changing mechanism was out of the question owing to the articulated spindles. The final step, so far as disc records are concerned, was to combine the two sound-tracks side-by-side on the same record, and this was arranged for by mounting dual cutting-heads on the recorder and twin pick-up heads on the reproducer, mounted on common radius arms. Synchronism now presented no problem, and the records become mechanically interchangeable with standard records on any type of machine, but the playing-time was of course reduced to half the normal. Four minutes of a 12-in. record became, on the other hand, four minutes of real pleasure, æsthetically more satisfying than double the period of even high-order unidimensional reproduction.

The scheme now came within measurable distance of a practical issue, though more obvious possibilities suggest themselves in the direction of film and other non-disc systems, in which the two sound-tracks could be accommodated without serious technical or material difficulty, and I have gone some distance in devising one form, suitable for ordinary use, in which it might be produced at little or no greater cost than any other high-class instrument.

That is as far as I have gone at present, but what I want to emphasize is the very real advantage that is realized in binaural reproduction, when everything possible has been done in the way of normal technique to secure a high order of fidelity. The effect, when a switch is arranged so that one of the channels can be cut in and out, is very marked, and it is interesting to compare the comparative flatness and lifelessness of otherwise good reproduction on a single channel, with the vivid realism that comes into being when both channels are switched in. Sitting with one's eyes closed, the sound seems to assume a definite form and location in space, that moves as the singer moves, and something very like a stereophonic effect occurs that is, of course, most marked on headphones where full binauralism is obtained, but is very appreciable on loud-speakers when they are suitably disposed in relation to the audience. The beauty and realism of the results seem to place them in a different category from even the best monaural technique, and lead me to believe that effort directed towards them will not, in the future, turn out to be effort wasted.

The possibilities of the scheme in regard to broadcasting, as distinct from gramophone reproduction, are of course much more remote, in so far as it may involve duplication not only of ether channels but of the whole transmitting and receiving chain. Practical experimental work is also more difficult to carry out. At the same time, in so far as it does not necessarily involve duplication of the whole chain, it gets nearer to practical politics, and I am inclined to think, as the result of work that has been done with channel-carrier systems, that the possibility is not nearly as remote as might be supposed. Given that the two channels can be transmitted on a single carrier, provided by one transmitter and received on one receiver, most of the objections to it disappear, and there is nothing basically impracticable in such a scheme. It is true that parts of the equipment will still have to be duplicated, and that a receiver problem is introduced that will have to be solved from the commercial standpoint. It is also true that the expense involved will be greater than it is at present; but it will not be anything like twice as great, and the issue resolves itself into the question " is it worth it ? " Æsthetically, I think it is. Practically, I think it might be if the thing were done and no alternative survived!

As it is possible that the author may be in a position to contribute to my information on the subject, I should like to ask him whether this is the case, and, if so, whether his conclusions have given him anything like the same encouragement as my own.

I also feel that I must second Mr. Turner's criticism of certain of the nomenclature employed in the paper. If " fidelity " means anything, what does " high-fidelity " mean, and what is " extra-high-fidelity " ?

Surely "fidelity," when we get it, will be virtue sufficiently rewarded!

Mr. H. L. Kirke: I should like to join with Mr. Willans in asking the author to say what he thinks is the reason for the blasting or distorting effect that was noticeable, particularly with the organ record.

The other point which I should like to take up with the author is one on which I have had many arguments with him in the past, namely the question of what seems to me to be the excessive and resonant low-frequency response associated with this particular instrument and a number of others. I was particularly conscious of the resonance, both in some of the records which were played and in the speech from the local station during the first demonstration.

The author refers to the difficulties of measuring the output from loud-speakers at very low frequencies, and here I am in entire agreement with him. Some of the measurements were made in a completely, or almost completely, " dead " room. It is very difficult to get a completely " dead " room, particularly at low frequencies, and this point, of course, has to be taken into

account in any measurements that are made. Further, the characteristic of the loud-speaker which is found in a " dead " room will not necessarily be the characteristic of the loud-speaker in a " live " room, because the reverberant characteristics of the room have an effect on the efficiency of output of the loud-speaker.

I have here a suggestion to make. It is of vital importance that any measurements which are made should be carried out in a room in which listening takes place, and, further, that those measurements should be representative. If one cannot make measurements that are really representative it is necessary to rely to a large extent on the ear, and I think that is what most people do. Another trick is to make a transient test, such as we have recently suggested in another connection in our own work. We can put into the loud-speaker a transient of some sort, and then listen to the sounds. If the sound is what one would expect from the wave-form of the transient, which can be measured or seen on any oscillograph, the loud-speaker reproduction is good; if it sounds " boomy," however, one can say that the loud-speaker reproduction is not good, and the instrument is probably resonating in the bass.

Dr. L. E. C. Hughes: In listening to sound reproduction one must be suspicious of one's own judgment, because it is certain that one cannot retain an impression of reproduced or any other sound for many seconds, and therefore, for aural estimation, comparison with a standard reproducing system or a sample of the original sound is essential (the author played a record of his own voice after reciting the words; this was greatly appreciated). In designing a sound-reproducing system, the engineer must be very certain what he is required to do. It is a fallacy to suppose that an original sound can be improved; if it is to be altered, the mode of alteration is arbitrary and therefore a subject of contention. The engineer must clearly ascertain all the relevant attributes of the sounds required to be reproduced, e.g. loudness, frequency range, acceleration, extent of blurring by reverberation, etc., and, within economic limits, design a system which treats all sounds alike according to the ascertained criteria. The author has shown a commercial reproducer which, when taken with the sound-recording apparatus, affords a good approximation to an ambitious specification. The controls, various degrees of tone control and contrast amplification, etc., are for the discretion of the user, remembering that the system as a whole is marred by extraneous radio noise and interference and record-surface noise, for which the designers of the equipment are not responsible and over which they have no control. The contentious element in obtaining the best response in adverse conditions is taken out of the hands of the engineers and left with the user. Since the radiogram is presented as a modern high-grade reproducer, it would have been useful to compare it with the Vitaphone gramophone shown here by Mr. Nash about 10 years ago. This was superior to any loud-speaker equipment in those days and, by comparison, would have afforded a measure of the intervening progress. The records played indicate a marked reduction of surface noise; is this an indication that superior material for records will shortly be available to the public? It seems a pity that so much attention is paid to the reproducers, if nothing is done to improve the material of the record. With regard to the long-playing high-fidelity needles, how can one tell when the useful life is at an end and that records are liable to be worn? I am fitting an automatic mechanism to count the number of times a needle is used, because it is difficult in practice to keep count up to, say, 50 records as a suggested safe life for the needle. In a tungstyle needle one can easily observe the point and judge whether it is safe to use further. I consider that two turntables are better than a record-changer and that two are easily justifiable in a *de luxe* model; discontinuities between records are completely abolished with easily acquired skill. I would plead for all issued multi-records of more than two sides to be pressed in staggered sequence (and incidentally to be more plainly marked) so that a continuous performance is possible for those who have two turntables. The B.B.C. set a good example in record playing, but presumably a double set of records is used.

Mr. L. A. Moxon: In connection with the sensitivity specification of the receiver, I should like to ask the author whether he can give any practical instances of conditions under which 1 μV sensitivity is useful. I should have thought such a specification was undesirable from the point of view of signal/noise ratio, in the case of receivers employing A.V.C. applied in the normal manner. If one considers a 100-μV station, the valve noise-level on it cannot be reduced below the equivalent of 1 per cent modulation, or something of that order. Now to receive such a station with the circuit arrangement described probably involves a 10 : 1 reduction of high-frequency valve slope, under the action of A.V.C. Valve noise being proportional to $\sqrt{I_a}/G$, there will be about a 3 : 1 increase of noise-level, and 3 per cent modulation of the signal will be serious. In addition the noise from the frequency-change valve is probably comparable with that from the high-frequency valve under these conditions.

In the receiver under discussion it is agreed that this criticism can be overcome by using the selectivity switch in a position giving less sensitivity and selectivity, but then interference, particularly what is called " side-band splash," will be much more prominent.

The only remedy I can see for this state of affairs is to delay the control of the first valve until a substantial measure of A.V.C. has been applied to the later valves.

Since noise generated in the receiver is the fundamental limitation to range, the use of high-magnification (tone-corrected) aerial circuits seems to be a big advance, and it would be interesting to know how the author has overcome (*a*) the difficulty of obtaining sufficiently accurate matching to keep errors well within the band widths of the circuits, (*b*) the variation in tone correction required as the signal frequency is varied, and (*c*) the obtaining of high magnification when screened leads are connected to the live ends of the tuned circuits.

I was surprised that the difference between the two high-fidelity positions should be such a small fraction of an octave. If this difference is noticeable it reminds us rather forcibly of the importance of increasing the frequency range to the upper limit of audibility. Has the author considered extending the range further with

the aid of a band-stop filter to cut out 9-kilocycle interference?

Was it found unnecessary to tap down on the short-wave oscillator circuit to stop short-wave frequency drift, or was some other precaution taken which is not immediately obvious? The series grid resistance shown, normally has the effect of greatly accentuating drift.

Turning to the gramophone side of the machine, I should be interested to know what success has been achieved in keeping the calibration of the speed control constant throughout its life.

In connection with cabinet resonance, the author mentions, as an alternative to a heavy and rigid cabinet, the use of a thin cabinet sufficiently damped by means of fibrous substances. For equivalent effectiveness this alternative gives substantial saving in cost and weight.

Mr. M. G. Scroggie: I should like to join with Mr. Bailey in questioning the policy of omitting a preselector stage on the short-wave band. I know that there are some designers who pay very little attention to second-channel interference on these wave-bands; in fact, they definitely prefer it on the ground that the listener receives many more stations! I should not like to suggest that that motive actuates the author, but it seems to me that if aerial pulling is to be avoided on short waves the coupling from the aerial to the frequency-changer has to be so loose that the signal/noise ratio is rather poor. I notice also that on the short-wave band the author provides a very much lower order of fidelity than he does on the other wave-bands, the reason being given that otherwise there would be risk of overloading the loud-speaker on strong telegraph stations. It seems to me, however, that the short-wave band offers one a much greater hope of getting high fidelity than the medium-wave band, which is so overcrowded, and some other means of avoiding the overloading trouble might profitably be sought.

The author obtains a flat frequency characteristic by setting off the intermediate-frequency circuits and the audio-frequency compensating circuits one against the other. I would point out, however, that a very small departure of either one or the other—probably of the intermediate-frequency circuit—would cause them to get out of register and give a result which would be worse than that due to an uncompensated system. Even if compensation to the degree specified in the paper is practicable in manufacture, it seems to me highly improbable that it would persist after the set has been bumped about the country and had valves renewed here and there.

Dr. R. C. G. Williams: Referring to the specification, several items appear to have been omitted, namely cost, calibration accuracy, and the type of mains supply for which the receiver is suitable.

Cost is an important engineering consideration and should be included in any complete specification.

Calibration accuracy contributes very largely to the entertainment value that the user will be able to obtain from the instrument, since it makes it easier for him to have a wider choice of programmes from the radio side, and, bearing on this, mention should also be made of the type of tuning indicator which is to be used, and whether station names are to be included on it.

With regard to the type of supply, the author limits the use to alternating current only, and, moreover, seems to avoid the commutator type of motor for driving the turntable—a point, of course, which it is rather difficult to get over with a d.c. supply.

A further minor point in the specification concerns the pick-up. A special needle is recommended, but it appears from the paper that although a moving-iron armature pick-up is used, the needle holder is not large enough to take the ordinary triangular fibre needle, and it would be interesting to have the author's comments on whether it is desirable to incorporate this feature.

On the subject of reliability I should like particularly to refer to the loud-speaker. For very good theoretical reasons the loud-speaker has a composite cone with a cement joint between an inner aluminium cone and an outer moulded paper cone. I should be glad to have some data on the reliability, particularly regarding the maintenance of the gap clearances, and the life of the joint in the cone.

Referring to reproduction, I cannot agree with the author's implied objection to a cabinet of comparatively thin wood backed by sound-absorbing material, since in my opinion considerations of cost and weight lead along this route and away from a solid wood cabinet of sufficient thickness to give the same freedom from wood resonances.

Regarding the general lay-out in the cabinet, the loud-speakers are mounted in the main body of the cabinet carcase with the receiver chassis acting as part of the acoustic damping for the volume of air enclosed behind the loud-speakers, and to me it would seem that this is likely to lead to trouble from chassis rattles and acoustic feed-back.

Mr. F. J. H. Charman: I am interested in high-frequency amplifiers, and I think that this is probably a suitable occasion to bring up the question of the relation between the high-frequency amplifier and tone correction. A few years ago some startling claims were made for a system in which the radio portion of the receiver attenuated the side-bands heavily, these side-bands afterwards being restored. One claim was that considerable reduction of the modulation of an unwanted station in an adjacent channel was effected. The subject was not understood very thoroughly at the time, and it was necessary to make some investigations in order to determine whether this phenomenon was of any practical utility. I was connected with an investigation of this type. We built a receiver in which a high-frequency amplifier attenuated the side-bands very highly—40 decibels in 5 kilocycles per sec.—and then we attempted to restore these side-bands in the audio amplifier. The first thing which was apparent was that most of the claims made for " mutual demodulation " were without foundation. It was found that anything which came into the pass-band of the receiver, however it was built, came through the other end of the amplifier, just as though it were a " flat " receiver right through and irrespective of where the " flatness " was obtained. Also, the whistle from the unwanted carrier came through in proportion to the overall response, and was not affected by the way in which it was obtained. The part which was lost was the intelligible modulation of the

station on the adjacent channel, and the removal of this modulation did not appear to give a very great gain in selectivity, owing to the objectionable nature of the other types of interference. Furthermore, when the question of tone correction arose it was very difficult to get an amplifier which would recover even 40 decibels at 5 kilocycles per sec. and still have some gain at the lowest amplifying frequency. The circuit went wrong if one tried to get more than 10 to 15 decibels at one stage, and at the lower frequencies, where the valves were unloaded, heavy distortion occurred in the valves. The design of the tone-corrected amplifier therefore became very troublesome and the amplifier was costly.

A point, which has not yet been mentioned in the discussion, in connection with the author's amplifier is that he uses mechanical adjustment of the band-width in the amplifier. Presumably it is cheaper to adjust the amplifier in that way. I have myself built amplifiers of the other type; in fact, I have actually applied the mathematics which Mr. Willans has given us. It is possible to build amplifiers according to that design, but one cannot put a circuit having a parallel impedance of about 2 megohms in the anode circuit of a valve whose resistance varies between 300 000 ohms and infinity, and expect to make the amplifier follow the law which is prescribed; and this has been a common mistake in receiver design. It means that one has to sacrifice something, namely stage gain, in order to produce an amplifier of prescribed and stable response. This method of design does help greatly in the design of an amplifier of adjustable band-width.

Amplifiers have been built in which the adjustment of the band is done electrically, but there is one difficulty which occurs. As soon as one switches in extra mutual impedance one alters the tuning of the amplifier. Thus about twice as many switches are required as would appear to be necessary at first sight, and the design becomes rather cumbersome. The mechanical system has the advantage, however, that one can adjust the amount of coupling in actual manufacturing processes.

Mr. F. S. Barton: I should like to ask the author whether he can give some figures with regard to intermediate-frequency break-through, to which no reference is made in the paper.

One or two speakers have referred to the difficulty of designing intermediate-frequency band-pass amplifiers. I am always at a loss to understand why they do not design a straightforward intermediate-frequency filter; it is perfectly calculable, realizable in practice, and does what one expects it to do.

With regard to the problem of sound absorption in radio cabinets, I should like to relate a little personal experience. I was visiting a friend recently whose radio-gramophone was giving unsatisfactory reproduction, and I was asked whether I could do anything to improve matters. I found that, despite the cabinet being fairly full of radio chassis, gramophone motor, etc., the addition of 2 lb. of cotton wool markedly reduced the cabinet resonance, with a corresponding improvement in the general quality of the reproduction.

Dr. K. R. Sturley: I should like to refer to the misuse of the term " high fidelity " in connection with the author's equipment. The radio-frequency side has, I think, 4 valves controlled by A.V.C., and these valves are biased right back on their characteristics when a strong local station is received; it seems to me fundamentally unsound to call equipment " high fidelity " when such enormous magnification is employed that the valves have to be biased to a part of their characteristic where they are more likely to give harmonic distortion. In the author's demonstration of the reception of Radio Luxembourg a very obvious heterodyne whistle was

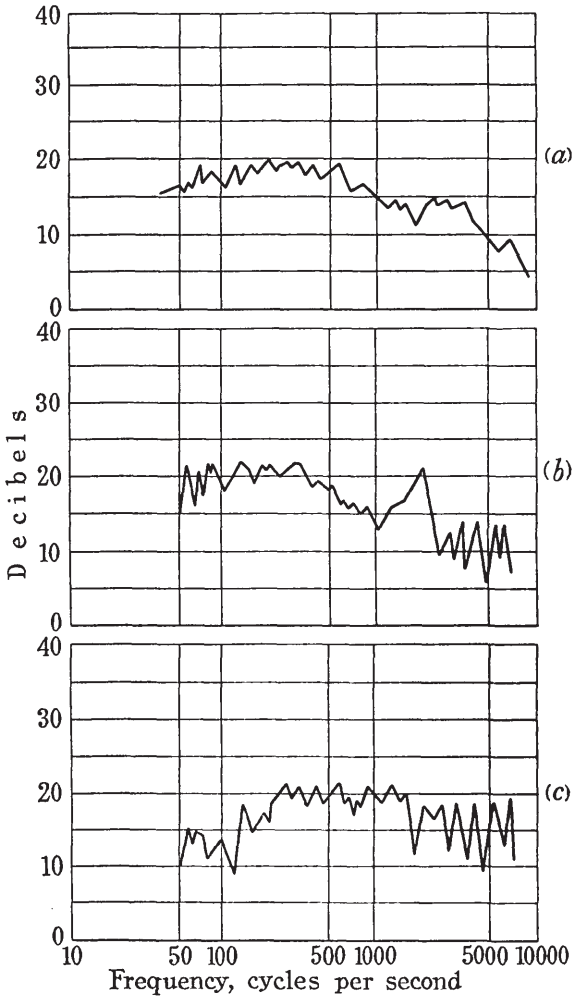

Fig. A.—Characteristics of various types of pick-up.
(*a*) Piezo.
(*b*) Moving-iron.
(*c*) Needle armature.

present. In rendering this whistle unobjectionable, high fidelity was thrown to the winds. It seems to me that the only stations that can provide a high-fidelity programme are the local stations, where all this amplification is superfluous. It would therefore, in my view, be sounder practice to cut out most of the amplification and utilize the high-frequency valves on that part of their characteristic where they may be reasonably expected to give less harmonic distortion.

Messrs. G. S. C. Lucas and **J. Moir** (*communicated*): In Section (6) of the paper, under the heading of " Gramophone Pick-ups," the author discusses the relative merits

of moving-coil, piezo-electric, and moving-iron pick-ups, and, while he is satisfied with the performance of the first and last of these, he criticizes the piezo-electric pick-up on account of its frequency characteristic and record wear.

The results of a large number of tests on various types and makes of pick-up carried out by us do not support this view, but indicate very definitely that as regards reduction in record wear, smoothness of frequency characteristic, and linearity of output, the piezo-electric pick-up can be made superior to either of the other types mentioned. Furthermore, the small dimensions and weight of the crystal element permit of a light and compact unit very suitable for handling and readily accessible for needle-changing.

damage to the pick-up. Other tests arranged to determine its life and operation over long periods indicated that this type of pick-up could more than hold its own with any other pick-up tested.

In Section (8), under the heading of "The Loud-speaker," the author shows characteristic curves for loud-speakers which are devoid of peaks, while the final curve taken in the listening room contains all the peaks and valleys associated with a loud-speaker response curve. From the description of the tests it would appear that the difference is attributed to the acoustic properties of the sound-dead test room and the average listening-room, and that all the peaks and valleys are due to standing waves in the room and not to the true response of the loud-speaker. It appears to us

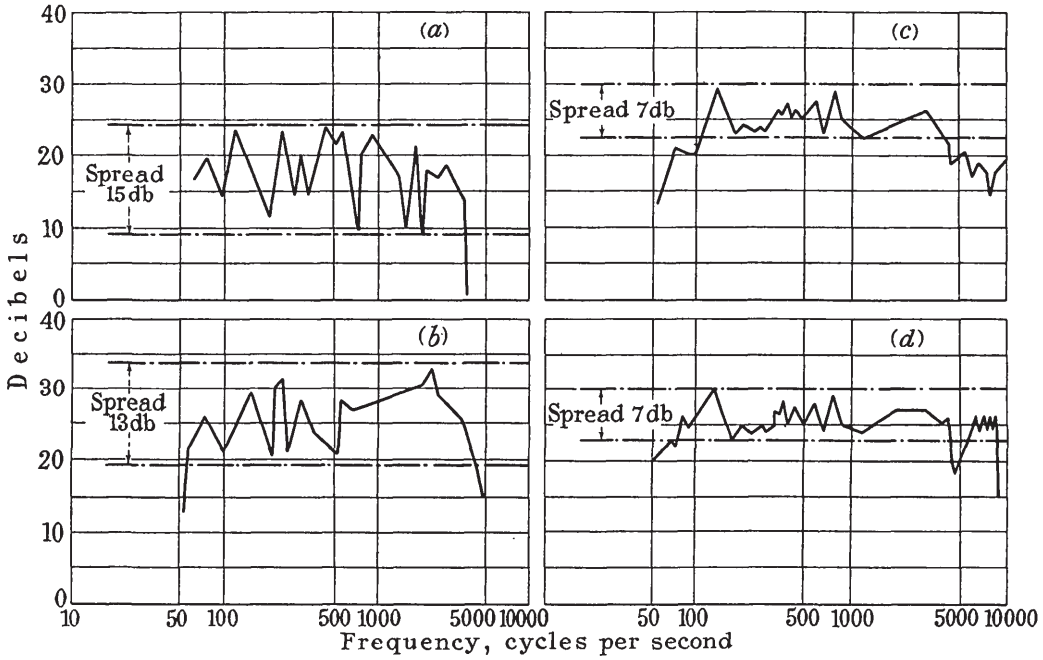

Fig. 18.—Characteristics of loud-speakers.

(*a*) R.K. loud-speaker, 1930.
(*b*) R.K. loud-speaker with baffle, 1932.
(*c*) Dual pair, 1934.
(*d*) Dual pair, 1935.

Fig. A shows typical frequency curves of moving-iron, needle-armature, and piezo-electric pick-ups, and it will be seen that the last has the best overall response—being relatively free from resonance peaks. The drop in output with increasing frequency is gradual and lends itself to simple compensation in the amplifier and circuit. The author's curves for the needle-armature pick-up are generally in agreement with the curve shown in Fig. 19 if the peaks and valleys are removed. We presume that the author has purposely left out the peaks and valleys from the frequency-characteristic curves.

The record wear produced by the piezo pick-up is less than for any other pick-up tested, good tracking being obtained with needle point weights as low as 40 grammes. The robustness of the piezo-electric pick-up was well demonstrated by a test consisting of raising the needle point 2 in. and allowing it to drop back on to the record. This test was repeated 8 000 times without sign of

that the true explanation will be found in the method of recording the acoustic output in the sound-dead test room. Tests extending over a number of years in sound-dead rooms, open air, and rooms and theatres of average acoustic properties, have established fairly conclusively that while the acoustic treatment surrounding the loud-speaker will have a pronounced effect on the position and amplitudes of the peaks and valleys in the response curve, these cannot be entirely removed by complete sound absorption. These results are confirmed by the test results given by H. R. Harbottle.*

Loud-speaker diaphragms, no matter how rigidly constructed, break up into a series of local resonance peaks producing peaks in the response characteristic. Modern loud-speaker cones of moulded material depend for their efficiency and smoothness of response upon an

* "Some Acoustic and Telephone Measurements," *Journal I.E.E.*, 1932, vol. 71, p. 605.

infinite series of local resonances in the cone, damped by losses in the material of the cone. Peaks and valleys produced by these resonances will be modified by the standing waves in the room, but will not be eliminated by complete elimination of standing waves.

The amplitudes of the peaks and valleys are of increasing importance in loud-speaker design, and the width of spread can be taken as a direct figure of merit of the speaker. It is now well established that a narrow spread in the amplitude of the peaks and valleys is of greater importance than an extension of the frequency range, and a system of recording loud-speaker response that does not take these into account cannot be considered satisfactory.

It may be of interest to note the improvement effected in the frequency range and peak amplitude spread over the last few years. The characteristics in Fig. B were taken in a standard test room with average acoustic treatment and show an extension of frequency range from 4 500 to 8 500 cycles, and a reduction in the resonance peak spread from $\pm 7{\cdot}5$ decibels to $\pm 3{\cdot}5$ decibels. It is hoped with further slight modification to reduce the spread to $\pm 2{\cdot}5$ decibels or even lower.

Dr. N. W. McLachlan (*communicated*): It is interesting to see that a pick-up having a uniform output over the frequency range covered by gramophone records is being used, the lateral amplitude of the armature being small enough to avoid non-linear distortion. The latter is a source of a good deal of poor reproduction with the average pick-up. The correction circuit of Fig. 13 eliminates the necessity for large amplitudes at low frequencies. It was first used by myself for pick-ups in 1928 and is described in Patent 328331. In the "Novotone" compensator it is used in the form of a transformer, thereby getting a step-up between the pick-up and the first valve. The actual correction curve of this instrument is within about 2 decibels of the theoretical curve, and the difference cannot be detected by ear.

Apart from M_1, S_1, and C_1, the diagram of Fig. 22(*b*) is not suitable for the electrical analogue of a conical diaphragm. Bending plays an important part in vibrations transmitted by a cone,* and a bending moment cannot be represented by known electrical quantities. The differential equation for the transmission of a longitudinal simple harmonic disturbance in a uniform straight bar is

$$\frac{d^2\xi}{dx^2} + a^2\xi = 0 \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

where ξ is the particle displacement at abscissa x, and a^2 is a positive constant. The equation for the transmission of flexural (bending) waves in a uniform bar is

$$\frac{d^4\xi_1}{dx^4} - b^2\xi_1 = 0 \quad . \quad . \quad . \quad . \quad . \quad (2)$$

where ξ_1 is the lateral displacement at abscissa x, and b^2 is a positive constant. Equation (1) takes the same form as that for electrical transmission in a uniform cable, so the mechanical case has an electrical analogue. Equation (2), however, is not of the second but of the fourth order, whilst the constant has a negative sign prefixed. Obviously equations (1) and (2) are not analogous, and it appears that an electrical analogue for a bar vibrating laterally cannot be found in terms of known electrical quantities. This being so, it follows that a cone cannot be represented by a transmission line as shown in Fig. 22(*b*).

With reference to the relative merits of aluminium and paper for cone construction, this question has been discussed in greater detail in section 16 of Chap. 18, and section 2 of the appendix in the reference cited above. It is not entirely a matter associated with the velocity of propagation in a uniform bar of the material, since the thickness of the conical shell is involved also.

Concerning the demonstration given by the author, I think a good deal of the low-frequency boom would disappear if the loud-speaker were designed to make the mean line of Fig. 23(*e*) level instead of having a downward slope as the frequency rises. Although the fundamental frequency of a diaphragm on its centring spider may be below audibility, there is the possibility that harmonics which occur at low audible frequencies may be important, as explained in section 6, Chap. 4, of the reference cited.

Mr. S. N. Ray (*communicated*): The high sensitivity (1 μV for $0{\cdot}5$ watt output) called for in the specification raises the question of quantitative data for signal/noise ratio. It would be interesting to know what is the voltage at the first valve grid for 1 μV induced in the aerial in the different wave-bands. The author mentions that a high gain is obtained with "litz"-wound coils. A high-impedance coil of this type will give a thermal noise of the order of 5 μV, and it is difficult to see how a signal of 1 μV can give any useful output without a phenomenal aerial circuit gain. Figures giving the signal strength when the noise is equivalent to, say, 5 per cent modulation at different radio frequencies, would be appreciated. Further, is it correct to assume that the equivalent "shot" noise at the first grid is about 1 μV and therefore negligible compared with the thermal noise?

Mr. W. J. Brown (*in reply*): The non-linear distortion in the reproduction of organ music from a record, noticed by Mr. Willans and others, was due to the very high level at which the instrument had to reproduce under extreme conditions of playing to a large hall full of people, and the "blasting" was in no way due to bad tracking or amplitude distortion in the pick-up. This type of distortion is much more apparent at some distance from the receiver, when the sound is at a comfortable level, than when close up and the ear is being overloaded.

In reply to Mr. Willans's query regarding the use of certain formulæ which he mentions, we do use double-peaked over-coupled and under-coupled single-peaked circuits superimposed and adjusted experimentally. The design of the circuits used in this instrument was the result of empirical development rather than pure mathematical calculation, for the reasons stated in Mr. Cooper's remarks. Two of my engineers, Mr. J. W. Sparrowe and Mr. R. E. Spencer, have studied the effect of stray reactions on the formulæ and they have found

* See N. W. McLachlan: "Loud-speakers" (1934), section 6, Chap. 18.

that values of stray reactions which were easily attained in commercial designs had a disastrous effect on the shape of the response curve, even when only two cascade transformers were used, but in this instrument we use a further stage and the stray reactions are amplified by a large number, larger than the stage gain, and the properties of the circuits as forecast from a mathematical examination of the circuits in a " dead " form really give us an approximation to the right answer. The alternative is to attempt to measure the decrements of the circuit in actual operation, but this is tedious and almost impossible without making assumptions about the very reactions which one is trying to measure, and one is left with the necessity of designing the amplifier empirically.

Mr. P. K. Turner objects to my use of the term " extra high fidelity " on this instrument and asks for a new word which can be applied to " an equipment which is really faithful." I am afraid that I cannot offer any reasonable solution to his inquiry, but I would point out that in the early days of the development of this receiver we considered the use of the term " high quality," until we realized that if the originating programme were of poor quality, then the quality of the reproduction would obviously be poor also, although the fidelity of the receiver would still be good.

Mr. Bailey raises the question of the necessity of the provision for further pre-selection for short-wave reception, and suggests a higher intermediate frequency or an additional stage. A higher intermediate frequency was considered but was rejected because it was found very difficult to obtain satisfactory variable selectivity, and a slight sacrifice in the short-wave performance has resulted. We have found trouble arising from intermediate-frequency harmonics when they are fed back to earlier stages of the receiver; in the design of this instrument this trouble is taken care of by means of adequate screening.

Mr. Bailey mentions an out-of-balance effect which he has noticed when the bandpass circuit follows the frequency changer, but our results show that the overall selectivity curve is just as symmetrical as the intermediate-frequency curve.

The drift of the circuit constants also queried by Mr. Bailey has been taken care of in this receiver by the use of a plated ceramic condenser for tuning the " Q " coil.

I agree with Mr. Bailey that the A.V.C. delay on short waves should be as small as possible, and we have reduced ours to 2 volts.

Referring to Mr. Bailey's remarks on the measurement of audio harmonics and the damping of the high-note boost, the measurements were taken at a frequency of 1 000 cycles per sec. with the selectivity switch in the 8-kilocycle position, i.e. the top boost was in circuit. No runs were taken at the bass-cut position, but the increase in distortion is not serious, because the amplifier will not normally be fully loaded when this amount of bass-cut is used. The high-note boosting circuits are not critically damped, as it would be impossible to obtain a sharp cut-off with a critically damped system. The circuits used do, in fact, " ring " for a few cycles, but the decay is very rapid and the effect is usually inaudible.

Mr. Cooper's comments on contrast amplification bring forward the suggestion that general improvement would result if an inverse contrast expansion amplifier were used, in broadcasting, to replace hand monitoring at the originating studio.

Dr. Gordon-Finlay has touched on the extremely interesting question of binaural reproduction and I suggest that the results of his experiments should be made up into the form of a paper. We agree that binaural reproduction gives results which are far in advance of single-channel systems, and schemes similar to those described by Dr. Gordon-Finlay have been tried in this country and in America with considerable success. The chief difficulty is the transmission and the registration of two channels. No doubt the increasing use of short waves will solve the radio question.

We are in complete agreement with Mr. Kirke that measurements should be made in an average listener's room, in fact we show the characteristic of the machine in such a room. We have, however, no control over the reverberation characteristics from room to room, or the reverberation characteristic of the broadcasting studio, but we have attempted to make an adjustment for the usual type of variation by a bass-cutting and a top-cutting tone control. We admit that this does not deal with all cases, but a machine with greater flexibility would be unwieldy to operate. As a case in point, Mr. Kirke complains of low-frequency resonance in the speech from the local station during the first demonstration. This, however, was not complained of in the last demonstration of my voice. Does not this point to the fault being in the broadcasting studio conditions?

There is another effect which may cause boominess in speech. Many rooms are deficient in bass, i.e. frequencies below 100 cycles per sec., and deficient in high-frequency reverberation, but are relatively lively in the middle-frequency region. We have, unfortunately, no adjustment in the set to compensate for this condition, and if correction is attempted by manipulating the bass-cutting control the whole of the control will be needed. This will cause the reproduction to sound very bad. It is our experience that boominess or excessive bass is due to excessive response in the region of 150–500 cycles per sec. I think Mr. Kirke is wrong in naming it a resonant bass. The ear is very sensitive to musical balance. The response in the middle-frequency range 150–500 must be balanced with the articulation range 1 200–3 000 cycles per sec. The bass range below 150 cycles per sec. must be balanced with the range above 3 000 cycles per sec.

Dr. Hughes is interested in the apparent reduction of surface noise and in the life of the new high-fidelity needles. The reduction of surface noise has been brought about mainly by maintaining an even (overall) high-frequency response characteristic of the set, and grading the fall-away of the response with increasing frequency so that the ratio of music-level/surface-noise is a maximum. Chromium high-fidelity needles have a useful life depending on the degree of the fidelity. Extremely critical listeners can hear the wear after about 8 playings, but the record will receive little or no damage for many times this life. For moderate fidelity—i.e.

5 000 cycles per sec. top cut—the needle will last about 30–40 playings, according to the type of record.

A large number of sets of records of operatic and orchestral works are already available to the public, pressed in a staggered sequence, expressly for the purpose of using on automatic record-changers and to assist in the quicker change-over which is possible with a 2-turntable arrangement.

I can assure Mr. Moxon and Mr. Ray that a sensitivity of 1 microvolt is useful for reception of certain American medium-wave stations on winter evenings, and the increase of valve noise when considerable A.V.C. is made use of is not serious in this receiver, because the intermediate frequency is desensitized as the frequency range is increased.

I would point out to Mr. Moxon that we are not using straight impedance aerial coupling in this receiver and we get over the difficulties of matching components by imposing close test-limits. We do not compensate for the variation in tone correction required as the frequency is varied, but the radio-frequency circuits are adjusted to be satisfactory at approximately the middle of the broadcast bands.

In reply to Mr. Moxon's query in regard to the difficulties experienced with screened leads, we took precautions in the manufacture of these screened leads to keep the capacitance very low and at the same time maintain good power factor, and by this means the high magnification of the circuits is not seriously impaired.

Serious consideration has not been given towards extending the frequency range, as we can rarely use even 9 kilocycles on account of heterodynes, and stations do not transmit frequencies above this. In the design of this receiver we did not experience any appreciable increase in drift due to the use of the series grid resistance, and we took the precaution of placing the short-wave oscillator coil low down on the chassis so as to prevent drift due to general temperature-change, also we found that it was not necessary to tap down.

With regard to the point raised by Mr. Scroggie of possible misalignment of intermediate-frequency and tone-correction circuits, I do not feel that this is likely to be serious, as the maximum amount of tone correction is only 4 decibels.

I agree with Dr. Williams that cost is an important engineering consideration, but in this particular case the primary requisition was performance. When this instrument is to be run from d.c. mains it is necessary to employ a convertor, because the d.c. voltage is inadequate for the high output.

We did not consider the use of fibre needles with the new pick-up, because the treble cut-off frequency is too low to give high-fidelity results.

Loud-speaker cones which have been cemented in a manner similar to that employed on this instrument have been in good service for the past 3 years without showing signs of deterioration; also extended life-tests with the cones vibrating at 50 cycles per sec. have shown that the jointing in the cone is satisfactory.

Further to Mr. Charman's comments on the relationship between the high-frequency amplifier and tone correction, in this receiver we have made the selective circuits sharp enough just to eliminate the programme interference, and afterwards we make up the quality by tone correction.

I would refer Mr. Barton to the intermediate-frequency selectivity curves which are shown in Section (4) B, as I cannot understand what else is meant by "intermediate-frequency break-through." In view of the difficulties caused by variable selectivity we found that it was not economical to use a straightforward intermediate-frequency filter.

The point raised by Dr. Sturley regarding biasing-back the A.V.C.-controlled valves to a part of their characteristic where they are more likely to give distortion does not really apply to this instrument, as in the high-fidelity position the sensitivity of the receiver is very much reduced, so that we are actually working the valves on a fair part of their characteristic and the best quality is obtained from local stations.

In reply to Messrs. Lucas and Moir on the section of the paper dealing with gramophone pick-ups, it can only be stated that they have based their comparison of the various types of pick-up on very inferior moving-iron types. In spite of these speakers' suggestions to the contrary, the response curves shown in Fig. 19 of the paper are fully representative of the frequency characteristic of the pick-up described in the paper. The superiority of this characteristic over all three of those shown in Fig. A is at once evident. With regard to the very prominent peaks and valleys shown in Fig. A, we would suggest that these are due either to faulty pick-ups or to errors in measurement.

The position as regards record wear is similar, i.e. if comparison is made with poor moving-iron types the piezo pick-up will give better results, but this does not hold when comparison is made with the pick-up described in which the stiffness has been reduced to 1·5 megadynes per cm.

I am afraid that I cannot agree with Messrs. Lucas and Moir regarding the effect of sound-dead rooms. In fact, our experience is the complete reverse of theirs. If the resonant peaks, etc., are a characteristic of the speaker then they will be shown up by dead rooms or by open-air measurements. We have satisfied ourselves that our dead testing room is virtually non-reflecting by taking distance/amplitude readings from the point source of sound. When the speaker is taken into a normal living-room the characteristics may be changed considerably, and it is only by taking both characteristics that one can obtain a useful statement of performance.

The question of diaphragm break-up is mentioned in the reply to Dr. McLachlan.

We cannot agree that the characteristic of the loud-speaker in Fig. B represents anything useful. If these characteristics are taken in a live room then we should expect a much more complicated series of peaks and valleys, but if taken in a completely dead room they do not represent the true characteristics, since an R.K. speaker curve in 1930 did not contain peaks and valleys between 100 and 500 cycles. We assume either that the room is not completely dead or that the baffle is small and the interference between the back and front of the diaphragm is causing these violent fluctuations. However, since no testing data are given it is difficult to discuss the results.

We cannot agree with Dr. McLachlan's statement that the circuit in Fig. 13 of the paper is that of the Novotone compensator which was introduced by him some years ago. This, however, is not the proper place for controversies of this nature. We agree with Dr. McLachlan that the single electric transmission-line analogue is not strictly correct. Bending does play an important part. The approximate analogue does, however, serve a useful purpose. It shows, for instance, where the cone should be stiff and where flexible. It enables one to see a little clearer the action of a cone which is graded so that the piston action is gradually reduced to the centre area as the frequency rises. (The internal resistance and radiation resistances have been omitted in the diagram.) This gives a smoother response than would be obtained if the normal bell-type resonances of a uniform cone were relied on entirely without modification. We cannot agree regarding resonance in the middle-frequency range. The resonance of the cone on the spider is about 40 cycles per sec., but when the speech coil is properly matched to the output amplifier the damping is sufficient to swamp the resonance completely. The overtones or radial modes of the cone are damped beyond measurement by the felt peripheral support. The curves of the acoustic output were taken with a slow continuous variation of frequency and are not smoothed-out point-to-point measurements.

As regards the slope of the overall characteristic curve shown in Fig. 23(*e*), this is not entirely a matter of the speaker design, but one of flexibility of the tone control available. Fig. 23(*d*) shows the face-on characteristic of a large number of positions in an average listening-room. If the bass-cutting tone control is adjusted it can be made to compensate for the high absorption of frequencies above 1 000 cycles per sec. The Institution lecture theatre has a very small absorption of the middle range. This is beyond the tone control of the instrument and accounts for the boominess experienced.

With regard to Mr. Ray's queries, I regret that we are not in a position to supply the quantitative data suggested, but we can assure him that the " shot noise " is negligible compared with the " Johnson noise " in the first circuit.